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Research on Nonsteady Flow Induction

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A Flow Induction laboratory has been set up at The George Washington University for use in this project. Experimental work on the rotary jet and on the generation of rotary-jet pseudoblades through the utilization of propagating stall has produced encouraging performance results and useful new information. Additional observations have been made on the energetics of eddy formation. Improvements have been made in the design of rotary jets, and studies of further such improvements have been initiated.		

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(1) ABSTRACT

The program of rotary-jet experimentation that was earlier carried out by a subcontractor at the U.S. Naval Academy has been and is being continued in the new facility, using somewhat larger models. Tests on these models have yielded new, useful, and encouraging information. Experimental work on the generation of rotary-jet pseudoblades through the utilization of propagating stall in stationary cascades has also been continued in the new facility, and has led to the identification of the causes of the difficulties that have been encountered in this phase of the program so far. Remedial action has included important changes in the solidity and shape of the cascade. Also planned is an order-of-magnitude increase in the Reynolds number of the flow in these experiments.

An improved method has been developed for the selection and control of spin and coning angles in the design and fabrication of rotary-jet rotors.

Theoretical and experimental studies have been initiated of the possibility of improving rotary-jet performance through secondary-flow prerotation.

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Chief, Technical Information Division

New observations and studies have been carried out on the energetics of eddy formation in pulsating-flow ejectors.

(2) RESEARCH OBJECTIVES

The main objective of this research is to generate basic information on those processes in which momentum and available mechanical energy are transferred from a driving to a driven flow through turbulent mixing and the work of interface forces. Information is sought on a variety of transfer modes, on their generation and control, and on their relative potential merits in such specific applications as thrust and lift augmentation. Special attention is given to the least dissipative component of the energy transfer process -- the work of interface pressure forces (pressure exchange) -- and to the ways in which it may be promoted and utilized.

(3) STATUS OF RESEARCH EFFORT

The following is an account of the work done and of the progress made during this reporting period.

Facilities

All experimental activities on the rotary jet and on stall propagation have been moved from the U.S. Naval Academy to the GWU Campus, where a laboratory for exclusive use in this project has been set up, with a 400 cfm, 20 psig air supply and all the appropriate instrumentation, including a Laser Doppler Velocimeter.

All other experimental activities relating to this project -- studies of jet penetration, of the energetics of eddy formation, and others -- have continued to be conducted in pre-existing facilities on the GWU campus, but with new and improved equipment and instrumentation.

Rotary-Jet Studies

Encouraging results were obtained by the Giannotti team at the U.S. Naval Academy toward the end of their subcontracting term. For example, with a three-bladed rotor, a spin angle of 10° , a ratio of shroud throat area to total rotor nozzle area of 70, and a shroud length/diameter ratio of about 1.5, the measured thrust augmentation ratios (referred to the thrust of the isentropically-expanded primary alone) ranged from 1.52 to 1.63. When, to account for the losses attributable to the very small scale of the models tested, the thrust was compared to the measured thrust of the primary alone when expanded through a simply convergent nozzle, the thrust augmentation ratio was found to range from 2.48 to 2.62.

Similar results have been obtained, as far as performance is concerned, in the new facility on the GWU campus. Emphasis in the program has, however, been shifted from the simple measurement of performance to a search for better understanding of the details of the interaction and of the stability of the interfaces across which pressure exchange is effected. Much attention has, accordingly, been given to the procurement, assembly, calibration, and testing of the required instrumentation, and to experimentation with a variety of modes of flow visualization. In parallel with this effort, rotary-jet tests have been conducted on somewhat larger models than used previously, with constant-area shrouds. The primary purpose of these tests has been to identify and correct or remove extraneous factors

(such as leakages, "air curtain" effects at the merger station, flow separation at the nozzle entrances, viscous losses within the nozzles or on the rotor surface, nonuniformities in the flow entering the rotor, malfunctions of the air bearing, and others) that may adversely affect performance or vitiate observations and measurements. This work has yielded important information, including new criteria for rotor design.

In a separate analytical study (Ref. 1), rigorous relations have been developed for the manner in which spin and coning angles vary along a rotor nozzle, and, even more importantly, for the manner in which they affect each other. This information will prove of value in the selection and control of the geometries of future rotary-jet rotors.

In yet another study (Ref. 2), attention has been given to a variation from the "standard" rotary jet thrust augmenters, whereby the secondary flow would be imparted a prerotation through a stationary cascade of fixed or adjustable vanes immediately upstream of the merger station. A preliminary analysis has revealed that the performance improvement that can be derived from this arrangement in propulsion applications can be significant, particularly if residual deviations of the flow from the axial direction are eliminated through the use of straightening vanes at the augments exit. A comprehensive paper on this subject is being prepared for presentation at this year's Winter Annual Meeting of the ASME (Ref. 3).

Finally, experiments have been conducted in the GWU Water Tunnel on the penetration of jets (simulating the rotary-jet pseudoblades) into a

transverse stream. Special attention has been given to the effect of primary-nozzle cross section on the longevity of the pseudoblades (Ref. 4).

Propagating-Stall Experiments

The cascade used in these experiments was modified in two important ways -- (a) by more than doubling its solidity, and (b) by giving its passages a divergence in the meridional plane, thereby generating across it an adverse pressure gradient. Still no well-defined stalling pattern was detected either by hot-wire anemometry or by the frequency spectrum analyzer, even when the angle of attack of the vanes was increased to about 50° . It was only toward the end of this reporting period that it was realized that the difficulty that has been experienced all along in this particular phase of the program could be attributed to the fact that the Reynolds number of the flow through the experimental cascade has so far been too low to permit the expected instability to occur -- only about 1000, even with the air supply working at full capacity. Plans were then undertaken to remedy this difficulty, through temporary but a substantial boost of the air supply.

Study of the Energetics of Eddy Formation

In direct-flow-induction thrust augmenters, such as the ejector, the migration of finite-size eddies from each flow into the other gives rise to interface pressure forces which do work, thereby contributing a non-dissipative component to the transfer of mechanical energy. An additional dissipative component is also contributed, however, by the nonrecoverable kinetic energy of rotation that becomes stored in the eddies themselves as they are being formed.

In connection with a study of the effect of eddy scale on thrust augmentation, the need has arisen for experimental information on the energetics of eddy formation in the extreme case of a pulsating-flow ejector, where the eddies are vortex rings spanning the entire interaction space. Under these conditions, the transfer of momentum and energy from the driving to the driven flow takes place entirely through the work of interface pressure forces, hence with the least dissipation, but, according to preliminary analyses, the nonrecoverable kinetic energy of rotation within each eddy amounts to approximately 35% of the initial kinetic energy of the generating body of fluid.

An experimental study has been made of the formation of the vortex rings under various boundary conditions, with special attention to the manner and extent of entrainment of ambient fluid into the vortex and to the partitioning of translational and rotational energy in the fully formed vortex.

A comprehensive paper on this research is being prepared for presentation at this year's Winter Annual Meeting of the ASME (Ref. 5).

References

1. Garris, C. A., "An Analysis of Rotary-Jet Rotor Geometry", The George Washington University Tech. Rept. GWU-SEAS-TR-83-FI-1, January 1983.
2. Foa, J. V., "Effect of Secondary-Flow Prerotation on Rotary-Jet Performance - Part I - Preliminary Evaluation", The George Washington University Tech. Rept. GWU-SEAS-TR-83-FI-2, May 1983.
3. Garris, C. A., and Foa, J. V., "Effect of Secondary-Flow Prerotation on Rotary-Jet Performance", in preparation for presentation at the ASME Winter Annual Meeting in Boston, Nov. 13-18, 1983.
4. Delianides, Ted P., "Studies in Orifice Design for Rotary Jet Nozzles", GWU Honors Research Report, May 1983.
5. Irdmusa, J. Z. and Garris, C. A., "Energetics of Vortex Ring Formation", in preparation for presentation at the ASME Winter Annual Meeting in Boston, Nov. 13-18, 1983.

(4) CUMULATIVE LIST OF PUBLICATIONS

The following reports and publications have so far resulted from AFOSR support under this contract:

1. Foa, J. V., "Considerations on Steady-and Nonsteady-Flow Ejectors", Proceedings of the Ejector Workshop, Bergamo Center, Dayton, Ohio, August 3-5, 1981.
2. Foa, J. V., "Utilization of Propagating Stall in a Cascade of Vanes", Journal of Aircraft, 18, No. 6, 1981.
3. Irdmusa, J. Z., and Garris, C. A., "A Preliminary Study of Vortex Formation from Pulsed Jets", Proceedings of the Ejector Workshop, Bergamo Center, Dayton, Ohio, August 3-5, 1981.
4. Foa, J. V., "Direct Flow Induction", The George Washington University Tech. Rept., GWU-SEAS-TR-82-FI-1, March 30, 1982.
5. Irdmusa, J. Z., "Energetics of Pulsed Jets", Master of Science Thesis, The George Washington University, May 1982.
6. Garris, C. A., "An Analysis of Rotary-Jet Rotor Geometry", The George Washington University Tech. Rept., GWU-SEAS-TR-83-FI-1, January 1983.
7. Foa, J. V., "Effect of Secondary-Flow Prerotation on Rotary-Jet Performance-Part I-Preliminary Evaluation", The George Washington University Tech. Rept., GWU-SEAS-TR-83-FI-2, May 1983.

8. Garris, C. A., and Foa, J. V., "Effect of Secondary-Flow Prerotation on Rotary-Jet Performance", in preparation for presentation at the ASME Winter Annual Meeting in Boston, Nov. 13-18, 1983.
9. Irdmusa, J. Z., and Garris, C. A., "Energetics of Vortex Ring Formation", in preparation for presentation at the ASME Winter Annual Meeting in Boston, Nov. 13-18, 1983.

(5) PROFESSIONAL PERSONNEL

Prof. Joseph V. Foa served as Principal Investigator, with Prof. Charles A. Garris as Co-Principal Investigator, during the first half of this reporting period. Prof. Garris has been Principal Investigator, with Prof. Foa as Co-Principal Investigator, since September 1982.

Also participating in this project during this period have been three undergraduate students -- Ted Delianides, Hamid Ghorani, and Vicky Williams-- and four graduate students -- Mohammad Anjum, Jamshid Irdmusa, Nader Modanlo, and George Stamoulis.

Jamshid Irdmusa, a doctoral student, received his Master of Science degree while working under this program. His thesis dealt with the energetics of vortex formation and was titled "Energetics of Pulsed Jets".

(6) INTERACTIONS

Two papers were presented at the Ejector Workshop in Dayton, Ohio, in August 1981, and two are being prepared for presentation at the ASME Winter Annual Meeting in Boston, Mass., in November 1983 (see items 1, 2, 8, and 9 under CUMULATIVE LIST OF PUBLICATIONS, above).

(7) INVENTIONS

The rotary-jet arrangement in which the secondary flow is imparted a negative prerotation (see Rotary-Jet Studies, above) is a novel one. The idea was conceived by Professor Garris toward the end of this reporting period.

